



The relationship of handwriting ability and literacy in kindergarten: a systematic review

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Abstract

Evidence supports a link between handwriting and aspects of literacy, including both reading and writing. Most evidence, however, pertains to children from grade one and above, once foundation skills known to support emerging literacy have been established. The purpose of this systematic review is to synthesise the extant literature concerning measurement of handwriting and literacy and the relationships between these measures for kindergarten students (the first year of formal instruction). Following a systematic search of the literature, 17 studies involving 3343 participants were identified. Handwriting measures could be grouped into two categories—letter writing fluency and perceptual motor skills, while literacy measures addressed one or more of letter name and sound knowledge, phonological skills, word reading, writing composition, and spelling. Strong evidence was found for the impact of letter writing fluency on writing composition, and letter name and sound knowledge. In addition, there was moderate evidence for a relationship between letter writing fluency, spelling, word reading and phonological skills. Weaker evidence was found for the impact of perceptual motor skill proficiency on letter knowledge and spelling, word reading and phonological skills. However, as all intervention approaches focusing on letter forming fluency included perceptual motor skill practice or exposure, an important role for perceptual motor skill in both letter writing fluency and literacy may be inferred. This review has found preliminary evidence to support the facilitating impact of handwriting on the foundations of literacy in kindergarten. Further research into the effects of handwriting interventions on kindergarten literacy is indicated.

Keywords Kindergarten · Writing · Reading · Literacy · Handwriting · Emergent literacy

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Introduction

Literacy is an important life skill, with pervasive effects on access to education, work and the ability to carry out important tasks that are required for independent living. Literacy abilities encompass both reading and writing. Kindergarten is an important time for the development of foundational skills in reading, such as, connecting letters with their sounds and decoding text using knowledge of the alphabetic principle, as well as writing (using the alphabetic principle and handwriting abilities to generate text) (Ritchey, 2008). The kindergarten year, therefore, is recognised as an important stage for acquiring the skills needed for successful reading and writing (Bingham et al., 2017; Kim et al., 2015). Thus, it is important to understand factors that may support literacy acquisition in this foundation year.

Researchers have theorised that handwriting skill impacts both reading and writing abilities (Vander Hart et al., 2010). For example, handwriting has been linked to written expression quantity and quality for children from the kindergarten year and above (Alves et al., 2016; Arrimada et al., 2018; Graham et al., 1997; Kent et al., 2014; Limpo & Alves, 2017; Limpo et al., 2018; Puranik & Al Otaiba, 2012). This relationship has been explained by a theory of cognitive load (McCutchen, 1996). This theory proposes that through automatising of the mechanical tasks of writing, *vis a vis* handwriting, overall cognitive load is reduced and cognitive resources can be re-directed to more complex authorial writing processes including planning, sequencing and ideation, thereby improving writing quality. The mechanical act of handwriting has also been found to activate brain regions associated with reading whereas simply viewing letters does not (James, 2010). The possible facilitatory impact of handwriting on reading has been described as “action perception coupling” (Kiefer et al., 2015). Writing letters may create stronger letter recognition through the coupling process, and thereby aid early reading. In addition, accurately categorising letter symbols has been shown to be facilitated by variations in letter forms produced through handwriting (Li & James, 2016). In the current context of general concerns about literacy acquisition in kindergarten students (Le et al., 2019), a clearer understanding of the role of handwriting is needed as handwriting development may serve as a facilitator of literacy ability in this age group.

There are several factors involved in fluent handwriting in kindergarten. These include cognitive skills such as the recall and retrieval of letter names and forms and their associated motor patterns, and perceptual motor skills involved in the execution or reproduction of the letter form (Fears & Lockman, 2018; Feder & Majnemer, 2007; Frolek Clark & Luze, 2014; Rosenblum et al., 2003; Weintraub & Graham, 2000). Handwriting curricula in kindergarten, therefore, are comprised of both the establishment of foundation skills that support fluent letter writing, as well as letter writing practice. Studies have reported associations between underlying perceptual motor skills and handwriting ability. For example, visual motor ability has been associated with handwriting ability from kindergarten to grade five (Daly et al., 2003; Kaiser et al., 2009; Volman et al., 2006;

Weintraub & Graham, 2000). Specific fine motor dexterity skills such as speed of sequential finger movements and in-hand manipulation have also been associated with handwriting (Berninger & Rutberg, 1992; Cornhill & Case-Smith, 1996). Given the early stage of handwriting development in kindergarten, the relationship of letter writing and perceptual motor skills to literacy may be important.

Similarly, kindergarten literacy is characterised by the establishment of foundation skills that are known to support both reading and writing composition (Treiman, 2000). As a result, literacy markers for kindergarten can include phonological skills, word reading and letter name and sound knowledge (Castles et al., 2018). There are a wide variety of measures of literacy specific to the emergence of these skills in kindergarten. Phonological skills can be measured using tests that ask students to listen to and identify sounds (letter sound fluency) or listen to a word, then say it without part of the word (elision or phoneme deletion). Reading skills can be assessed at the letter level, such as initial letter recognition tests, or through asking students to read both real and nonsense words. As for literacy, measures of handwriting ability in kindergarten vary, and may be complicated by the emergence of perceptual motor abilities that could impact letter writing. It is not clear at this stage whether current handwriting measures adequately account for these factors, with some researchers noting a floor effect in commonly used methods such as alphabet writing (Puranik et al., 2017). Therefore, in order to interpret relationships between handwriting and literacy, it is important to establish groupings of both handwriting and literacy measures based on similarity of the construct being measured.

The purpose of this systematic review is to determine the relationship between handwriting and literacy in kindergarten. A synthesis of measures for both handwriting and literacy and an analysis of relationships and effects are important steps in understanding the interactions between these factors. Specifically this review sought to answer the following questions:

1. What are the characteristics of handwriting and literacy measures in kindergarten?
2. What are the observed relationships between handwriting ability and literacy in kindergarten?

Method

The methods and reporting of this review were guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Moher et al., 2009). The program Covidence was used to manage the search results and selection process.

Eligibility criteria and information sources

A systematic search was undertaken of CINAHL, Eric, A + Education, PsychINFO and Scopus from 1998 to September 2017, and an identical search to the initial search conducted in September 2017 was conducted in January, 2020. The steps

involved in this repeated search included re-running the exact syntax in each of the data bases, using the same search terms. The total of 1179 articles identified as relevant and requiring further review was the sum of these two searches, with duplicates removed, plus seven articles identified by hand search. The year 1998 was selected as the start date for the review as the following year the National Research Council in the United States published a comprehensive report describing the critical skills that beginning readers need to acquire (Burns et al., 1999). A process was used to refine and add to the search terms to ensure that all possible relevant articles were captured by the final search. This method was used to maximise the returns relevant to the review question. A list of search terms for handwriting, literacy and kindergarten was generated by the authors based on a broad literature review, and these terms were entered into one data base (CINAHL). The results of this initial scoping search were reviewed in detail to identify additional terms that were used to describe each category. Any additional terms were then added to the review search terms. This process confirmed and ensured that all terms relevant to handwriting and literacy, as well as terms used to describe the kindergarten year were included. The refined search terms were then used to search the five identified data bases. After the electronic search and screening processes (described below, Study Selection), an additional hand search strategy was employed by reviewing the reference lists of the included studies. This method was selected to cross check the electronic results, as the reference lists of the included studies contained highly relevant authors and articles specific to the search terms. A further forward hand search methodology was also undertaken to identify any articles citing the included papers that met both the search terms and the time frame for the review.

Terms used for the CINAHL search are listed in Table 1 and included literacy and handwriting concepts. The participant population was restricted to the first year of formal schooling. Where necessary, clarification from study authors was sought to confirm that the population studied were in their first year of formal instruction, and that this year included curriculum prescribed academic activities. The inclusion criteria were: article published in or after 1998; English language publication available; studies conducted in language other than English where English language text available; relationship between handwriting and literacy reported; participant population in first year of formal schooling; any study design including quantitative and qualitative; and published articles or dissertations. Exclusion criteria included: narrative review or opinion; and studies prior to 1998.

Study selection

The electronic search strategy yielded a high number of articles that met the search terms (1202, see Fig. 1) and the hand search strategy yielded an additional seven articles. After duplicates were removed, 1179 articles were reviewed by title and abstract by two authors (KR and KT) and studies that met the search criteria were identified. A third author (KD) reviewed any studies where a conflict had occurred. In the second stage of the review, two authors (KR and LR) reviewed 100 identified articles that met the search criteria by reading the full

Table 1 Search Strategy used in CINAHL

#	Query	Results
S1	(MH "Handwriting") OR "handwriting"	1108
S2	"pre writing skill*"	5
S3	"prewriting skill*"	7
S4	pencil* n3 control*	9
S5	"grapho-motor"	7
S6	grafo-motor	1
S7	"drawing proficiency"	1
S8	"fine motor skills"	246
S9	printing n3 skill*	2
S10	proficient at-risk non-proficient writer*	1
S11	(upper limb*) n3 (speed or dexterity)	58
S12	(word* or letter* or printing*) n3 (legib* or speed)	154
S13	"writing readiness"	8
S14	S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12 OR S13	1541
S15	(student* or school*) n5 (elementary or preschool* or early stage or kinder* or infant* or prep* or pre-k)	14,778
S16	"emergent writer*"	3
S17	"foundation phase learner*"	3
S18	"school beginner*"	10
S19	S15 OR S16 OR S17 OR S18	14,831
S20	S14 AND S19	90
S21	(school* or student*) n5 (primary or junior or secondary or high or middle or elementary)	39,632
S22	S19 OR S21	44,405
S23	S14 AND S22	130
S24	"early literacy skill*" OR (MH "Literacy")	4587
S25	"emergent literacy"	177
S26	encoding	5949
S27	grapheme phoneme	92
S28	letter* n3 (identification or naming fluency or recognition)	149
S29	"orthographic motor integration"	30
S30	phoneme segmentation	20
S31	phonological n3 (segmentation or awareness or processing or skill*)	1118
S32	rapid naming	171
S33	(MH "Writing") OR "writing"	21,399
S34	"written expression" OR (MH "Written Language")	273
S35	"written productivity"	8
S36	S24 OR S25 OR S26 OR S27 OR S28 OR S29 OR S30 OR S31 OR S32 OR S33 OR S34 OR S35 OR S36	33,066
S37	S14 AND S19 AND S36	28
S38	S14 AND S22 AND S36	46

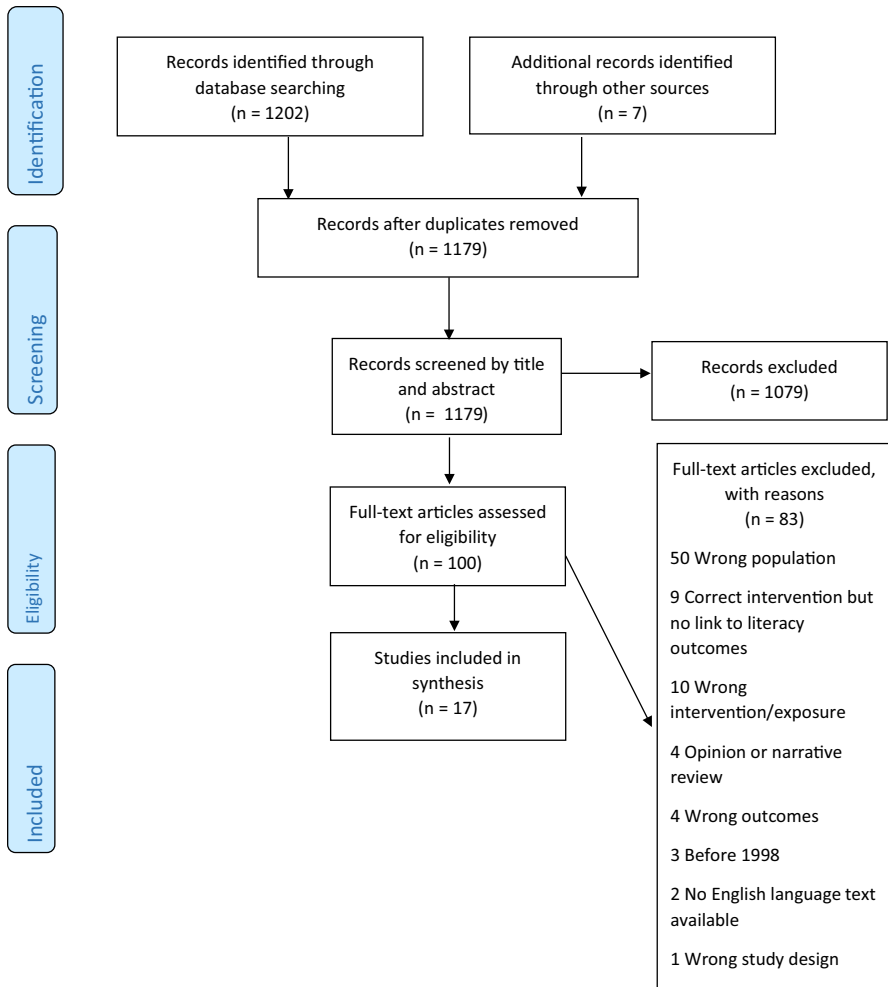


Fig. 1 PRISMA flow chart

text. Again, a third reviewer (KD) provided the casting vote for conflicts. Most studies were excluded at this point because, on closer examination, and in consultation with study authors where needed, the participant population did not meet the criteria of the first year of formal instruction (see Fig. 1). This was an important criteria, as this systematic review was specifically examining handwriting and literacy relationships for children in the first year of instruction, when handwriting is generally taught formally for the first time. A hand search of the reference lists of the included studies was conducted to identify any additional articles that met the search criteria. This method was selected to cross check the electronic results, as a high number of relevant studies, encompassing dissertations and published articles, were included in the full text screening. Four

additional articles that met the inclusion criteria were identified using this hand search method. An additional forward search strategy was employed to identify any articles, published within the search period, that cited the included studies identified by the electronic and hand search. Two relevant studies were identified using this method, including an article and a dissertation. An additional article was identified on peer review that was published shortly after the date of the second electronic search, and this article was included in the review process in the interests of completion. A total of 17 studies were identified through the selection processes employed in this review, comprising both electronic and hand search methods.

Data items and collection processes

Data from the included papers were extracted into Excel 2007 by KR and checked by KD for accuracy. Extracted data included:

- Study characteristics—design, year of publication, participant numbers, study quality
- Participant age range
- Intervention (if relevant)—intervention approach and duration
- Handwriting measures
- Literacy measures
- Significant results for relationships/associations between handwriting and literacy

Risk of bias assessment

The Johns Hopkins nursing evidence based practice rating scale (Dang & Dearholt, 2017) was used to assess included studies for quality. The rating scale uses a flow chart to establish evidence level and quality rating. Level of evidence is established through evaluation of three quality factors including independent variables, control and randomisation. The three levels of evidence are randomised control trials (Level 1), quasi-experimental studies (Level II), and non-experimental studies (Level III). Quality rating is determined using a fifteen point checklist and studies are classified as high quality (A), good quality (B), or low quality (C) based on the quality assessment. The quality rating of studies included in this review was used to identify the weight of evidence, with evidence from higher rated studies noted in the results and discussion. All studies in this review were either quasi- or non-experimental, restricting evidence to Level II and III. The quality of the included studies was generally good, with all being rated at level B. Limitations in quality generally related to currency of literature review, consistency between intervention and control groups and use of valid and reliable measurement instruments. Quality rating for these ($n=3$) was only applied to individual sub studies relevant to the review question.

Results

The process of identification and selection of studies is illustrated in Fig. 1. From 1179 citations, a total of 17 studies were identified for inclusion in the study (see Fig. 1). The significant associations or effects between handwriting measures or interventions and literacy are shown in Table 2.

Characteristics of included studies

Seventeen studies were included in the review. Some studies used more than one study design. Designs comprised quasi-experimental ($n=4$), longitudinal ($n=6$) and cross sectional research ($n=12$). Theory testing was included in three studies. Although no study design was excluded from the search, the nature of the search terms meant that no qualitative studies were identified. The mean age for participant populations in studies where age was reported ($n=12$) ranged from 61.6 to 74.2 months. The total number of participants in the included studies was 3343. An overlap in participants was observed across some studies ($n=4$). Studies were conducted in the United States of America ($n=12$), Australia ($n=3$), Canada ($n=1$), and Norway ($n=1$). Study design description relates to outcomes that are the focus of this review. For example, in a two group study, Dolin (2016) measured differences in handwriting legibility at pre- and post-test, however written composition was a post-test measure only. As the subject of this review is the association and relationships between handwriting factors and literacy outcomes, this study has been described as a two group post-test design. Similarly, Duncan (2019) conducted analysis of the impact of transcription (spelling and handwriting combined) on writing composition outcomes, however for this review, only the direct relationships between the handwriting measure and the writing composition measures are reported in the results. Where relevant, the results of the wider analysis conducted in studies, such as Duncan (2019), are reported in the discussion. Table 2 summarises study characteristics including design, participant population details and describes handwriting intervention or measures. Not reported (NR) data are noted where applicable.

Question 1: What were the characteristics of handwriting and literacy measures in kindergarten?

A variety of measures were used by authors to assess handwriting and literacy (see Appendix Table 3). Handwriting measures could be classified into two sub-categories—letter writing fluency (dictated randomly or alphabetically sequenced) and perceptual motor skills. Literacy measures fell into one of five sub-categories—letter name and sound knowledge, phonological skills, word reading, writing composition and spelling. The measures used included foundational skills known to impact kindergarten handwriting and literacy, for example, letter name and sound knowledge, phonological awareness skills, and visual and fine motor skills. Fluency was

Table 2 Results by author for study design, quality rating, participants and significant effects/associations

Number	Author, year, title	Design (quality rating)	Participants N, Mean age (SD)	Kindergarten handwriting measures/ interventions	Significant associations or effects of kindergarten handwriting skills on literacy ^a
1	Bazyk et al. (2009) <i>Integrating occupational therapy services in a kindergarten curriculum: A look at outcomes</i>	One group pre- post-test (IIB)	37, 71.5 months (NR)	Embedded occupational therapy intervention 2 days per week for seven months, including teacher consultation (64%) and individual and group fine and visual motor and sensory processing activities targeting participation in class activities and writing (36%)	Post intervention effects for correct letters in dictated sentence, $\eta^2 = 0.336^{**}$; upper and lower case letter identification (untimed), $\eta^2 = 0.696^{***}$
2	Dolin (2016) <i>An analysis of the effectiveness of curriculum embedded handwriting instruction and its impact on student learning</i>	Two group post-test (IIB)	313, NR (NR)	36 weeks of daily handwriting curriculum lessons (Handwriting Without Tears) using multi-sensory mediums (visual modelling, auditory cues and sensory practice for letter formation) and feedback delivered by teachers after 6.5 h training. Control condition in regular classes not described	Intervention group higher scores at post-test in writing composition measures including words spelled correctly, $f_{(1,311)} = 4.322^*$; and number of ideas, $f_{(1,311)} = 6.298^*$
3	Duncan (2019) <i>Examining the dimensionality and contributors of kindergarten composition</i>	Cross sectional (IIB)	282 72 months (NR)	Dictated letter writing accuracy (upper and lower case alphabet letters dictated in fixed, random order; scored on scale of 2 points for correct and well formed letters, one point for correct and recognisable but poorly formed letters, and zero points for incorrect, blank or extremely poorly formed letters)	Associations between lower and upper case letter writing accuracy and: real word spelling, $r = 0.48-0.55^{**}$; nonsense word spelling, $r = 0.40-0.52^{**}$; writing composition quality, $r = 0.39-0.49^{**}$; and writing composition productivity (number of words and ideas), $r = 0.26-0.35^{**}$

Table 2 (continued)

Number	Author, year, title	Design (quality rating)	Participants N, Mean age (SD)	Kindergarten handwriting measures/ interventions	Significant associations or effects of kindergarten handwriting skills on literacy ^a
4	Eidnitz-Neufeld (2003) <i>Early letter form errors as a predictor of later literacy outcomes and the short- and long-term benefits of early instruction in proper letter formation</i>	Cross sectional and longitudinal (Study 1; IIB) Two group post-test intervention (Study 2b; IIB)	Study 1: Cohort A 52, NR (NR), cohort B 35, NR (NR) Study 2b: Cohort A 92 (40 experimental, 52 control), NR (NR)	<p>Study 1 Dictated letter writing errors (13 letters dictated randomly, written from memory scored correct/incorrect based on legibility)</p> <p>Study 2b Direct instruction in letter formation (Jolly Phonics) delivered by teacher over one year after 2 h teacher training program. Weekly instructional activities provided for one to four new sounds for graphomotor letter formation, phonological development, and letter sound correspondences using multi sensory activities to practice letter formation. Home practice included Control condition received standard teaching</p>	<p>Baseline dictated letter writing errors negatively associated with: 1. Kindergarten letter naming ability: Cohort A, $r = -0.796^{**}$; Cohort B, $r = -0.384^{**}$ 2. Grade three (Cohort B) word reading, $r = -0.395^{**}$; nonsense word reading, $r = -0.349^{**}$; reading comprehension, $r = -0.485^{**}$; reading speed, $r = -0.434^{**}$; and spelling, $r = -0.313^{*}$ 3. Grade five (Cohort A) word reading, $r = -0.475^{**}$; nonsense word reading, $r = -0.429^{**}$; reading comprehension, $r = -0.458^{**}$; reading speed, $r = -0.567^{**}$; spelling, $r = -0.527^{**}$; and writing composition, $r = -0.509^{**}$</p> <p>Study 2b Intervention group attained higher scores in grade five writing composition, assessed for conventions, linguistics and concepts, $r = 2.122^{*}$</p>

Table 2 (continued)

Number	Author, year, title	Design (quality rating)	Participants N, Mean age (SD)	Kindergarten handwriting measures/ interventions	Significant associations or effects of kindergarten handwriting skills on literacy ^a
5	Frolek Clark and Luze (2014) <i>Predicting handwriting performance in kindergartners using reading, fine-motor and visual-motor measures</i>	Cross-sectional (IIB)	48, 74.2 months (4.23)	<p>Dictated letter writing accuracy (26 randomly dictated alphabet letters, scored correct if all five features achieved, including phoneme, grapheme correspondence, closure, line placement, no large gaps, and correct orientation)</p> <p>Dictated letter writing speed (time to write each dictated letter)</p> <p>In-hand manipulation (manipulation of objects in dominant hand)</p> <p>Visual motor integration (copy shapes)</p> <p>Visual perception (identify matching shapes)</p> <p>Motor Coordination (draw within boundary lines of a shape)</p>	<p>Kindergarten associations between Dictated letter writing accuracy and Initial sound fluency (ISF), $r = 0.726^{**}$; letter naming fluency (LNF), $r = 0.676^{**}$; phoneme segmentation fluency (PSF), $r = 0.600^{**}$; nonsense word fluency (NWF), $r = 0.633^{**}$</p> <p>Dictated letter writing speed and ISF, $r = 0.357^{**}$; LNF, $r = 0.510^{**}$; PSF, $r = 0.386^{**}$; NWF, $r = 0.495^{**}$</p> <p>In hand manipulation and ISF $r = 0.329^{*}$; LNF $r = 4.10^{**}$; PSF $r = 0.458^{**}$; NWF $r = 0.329^{*}$</p> <p>Visual motor integration and ISF, $r = 0.465^{**}$; LNF, $r = 0.529^{**}$; PSF, $r = 0.465^{**}$; NWF, $r = 0.453^{**}$</p> <p>Visual perception and ISF $r = 0.387^{**}$; LNF, $r = 0.292^{*}$; PSF, $r = 0.385^{**}$; NWF, $r = 0.373^{**}$</p> <p>Motor coordination and ISF, $r = 0.361^{*}$; LNF, $r = 0.353^{**}$; PSF, $r = 0.357^{**}$; NWF, $r = 0.374^{**}$</p> <p>Intervention group improved in quality of writing composition at post-test ($t = 6.79^{***}$) and delayed post-test ($t = 12.55^{***}$)</p>
6	Jones and Christensen (2012) <i>Impact of teacher professional development in handwriting on improved student learning outcomes and writing quality</i>	Two group pre- post-test intervention study (IIB)	381 post test, 275 delayed post-test, 65 months. (NR)	<p>Intervention program of two different types of teacher training. Experimental condition received 1 h teacher professional development in handwriting explicit instruction including modelling, sensory motor practice, directional arrows, memory retrieval and contextual writing</p> <p>Control condition received 1 h training on standard curriculum</p>	<p>Intervention group improved in quality of writing composition at post-test ($t = 6.79^{***}$) and delayed post-test ($t = 12.55^{***}$)</p>
7	Karlsdotir and Stefansson (2003) <i>Predicting performance in primary school subjects</i>	Longitudinal (IIB)	407, 84 months (NR)	<p>Dictated letter writing (capital letters)</p> <p>Visual motor integration (copy shapes of increasing complexity)</p>	<p>Dictated letter writing predicted:</p> <ol style="list-style-type: none"> Grade two reading, $r = 0.51$ (99% CI 0.43, .58); and spelling $r = 0.57$ (95% CI 0.50, 0.65) Grade five reading, $r = 0.46$ (95% CI 0.38, .53); and spelling $r = 0.45$ (95% CI 0.37, 0.52)

Table 2 (continued)

Number	Author, year, title	Design (quality rating)	Participants N, Mean age (SD)	Kindergarten handwriting measures interventions	Significant associations or effects of kindergarten handwriting skills on literacy ^a
8	Kent et al. (2014) <i>Writing fluency and quality in kindergarten and first grade: The role of attention, reading, transcription and oral language</i>	Cross sectional including theory testing, and longitudinal (IIB)	265, 61.6 months (NR)	Alphabetic letter writing fluency	Alphabetic letter writing fluency associated with: 1. Kindergarten reading, $r=0.51^{***}$, spelling, $r=0.054^{**}$, and writing composition (number of words, sentences, ideas, and correct word sequences) $r=0.47^{**}$ 2. Grade one writing composition quality (text structure, ideas, word choice and sentence fluency), $r=0.31^{**}$, and writing production (correct word sequences), $r=0.34^{**}$ Alphabetic letter writing fluency uniquely and positively related to kindergarten composition fluency, $\beta=0.13^*$
9	Kim et al. (2014) <i>The contributions of vocabulary and letter writing automaticity to word reading and spelling for kindergartners</i>	Cross sectional including theory testing (IIB)	242, 70.0 months (7.3)	Alphabetic letter writing fluency	Alphabetic letter writing fluency associated with kindergarten phonological awareness, $r=0.48^{**}$; alphabet knowledge fluency (letter name and sound), $r=0.53^{***}$, word reading, $r=0.37^{**}$; and spelling, $r=0.48^{**}$, and marginally related to spelling in structural equation modelling ($\beta=0.11$, $p=0.06$)
10	Kim et al. (2011) <i>Componential skills of beginning writing: An exploratory study</i>	Cross sectional including theory testing (IIB)	242, 70.0 months (7.3)	Alphabetic letter writing fluency	Alphabetic letter writing fluency associated with latent kindergarten variables of reading, $r=0.36^{**}$; spelling, $r=0.47^{**}$; and composition writing (number of words, ideas and sentences), $r=0.46^{**}$, and uniquely and positively related to kindergarten written composition, $\beta=0.26^{**}$
11	Kim et al. (2015) <i>Kindergarten predictors of third grade writing</i>	Cross sectional and longitudinal (IIB)	157, NR (NR for kindergarten data collection point)	Alphabetic letter writing fluency	Alphabetic letter writing fluency associated with: 1. Kindergarten letter and word reading, $r=0.32^*$; word attack (nonsense word reading), $r=0.30^*$; sight word efficiency (fluency), $r=0.31^*$; dictated spelling, $r=0.41^*$; real sight word spelling, $r=0.53^*$; real decodable word spelling, $r=0.39^*$; and literacy variable (composed of six measures of word reading and spelling), $r=0.35^*$ 2. Grade three exposition idea development, $r=-0.23^*$

Table 2 (continued)

Number	Author, year, title	Design (quality rating)	Participants N, Mean age (SD)	Kindergarten handwriting measures/ interventions	Significant associations or effects of kindergarten handwriting skills on literacy ^a
12	Malpique et al. (2020) <i>Writing and reading performance in Year 1 Australian classrooms: Associations with handwriting automaticity and writing instruction</i>	Cross sectional and longitudinal (IIB)	154, 70.0 months (7.3) for kindergarten data collection point	Alphabetic letter writing fluency (kindergarten data collection point only used in this review)	Alphabetic letter writing fluency associated with: 1. Kindergarten word reading, $r=0.32^{**}$ 2. Year 1 writing composition quality, $r=0.54^{**}$; writing production (number of words), $r=0.34^{**}$; and word reading, $r=0.42^{**}$ Alphabetic letter writing fluency predicted year 1 writing quality, $B=0.04^{***}$; and year 1 word reading, $B=0.53^{***}$
13	Malpique et al. (2017) <i>Handwriting automaticity and writing instruction in Australian kindergarten: An exploratory study</i>	Cross sectional (IIB)	177, 70.0 months (4.2)	Alphabetic letter writing fluency	A one unit increase in word reading was associated with a .10 increase in alphabetic letter writing fluency, $\beta=0.10^{**}$
14	Puranik and Al Outhba (2012) <i>Examining the contribution of handwriting and spelling to written expression in kindergarten</i>	Cross sectional including theory testing (IIB)	242, 62.8–70.2 months (4.6–5.5)	Alphabetic letter writing fluency	Alphabetic letter writing fluency associated with kindergarten total number of words written in a composition, $r=0.44^{***}$; ideas expressed in a composition, $r=0.43^{***}$; spelling, $r=0.48^{***}$; word attack (reading nonsense words) and word identification, $r=0.24^{***}$ Alphabet letter writing fluency uniquely and positively related to kindergarten writing outcome, $\beta=0.24^{***}$ and accounted for the most unique variance (4.1%) in total number of words in kindergarten composition

Table 2 (continued)

Number	Author, year, title	Design (quality rating)	Participants N, Mean age (SD)	Kindergarten handwriting measures/ interventions	Significant associations or effects of kindergarten handwriting skills on literacy ^a
15	Puranik et al. (2017) <i>Examining alphabet writing fluency in kindergarten: Exploring the issue of time on task</i>	Cross sectional and longitudinal (IIB)	134, 69 months (4)	Alphabetic letter writing fluency at beginning and end of kindergarten using timed – 15 s (15 s) and 60 s (60 s) or untimed (ut) tests	<p>Cross-sectional correlations of alphabet writing fluency at beginning of year with words written in a sentence (15 s, $r=0.42^{**}$; 60 s, $r=0.63^{**}$; ut, $r=0.66^{**}$), sentence writing quality (15 s, $r=0.41^{**}$; 60 s, $r=0.63^{**}$; ut, $r=0.62^{**}$), composition words written (15 s, $r=0.26^{**}$; 60 s, $r=0.58^{**}$; ut, $r=0.61^{***}$), composition quality (15 s, $r=0.37^{**}$; 60 s, $r=0.59^{**}$; ut, $r=0.58^{***}$), spelling (60 s, $r=0.47^{**}$; ut, $r=0.49^{***}$) and standardised assessment of writing (60 s, $r=0.55^{**}$; ut, $r=0.55^{***}$)</p> <p>End of kindergarten alphabet letter writing fluency associated with end of year spelling (15 s, $r=0.46^{**}$; 60 s, $r=0.46^{**}$; ut, $r=0.45^{***}$), standardised assessment of writing (15 s, $r=0.48^{**}$; 60 s, $r=0.51^{**}$; ut, $r=0.57^{***}$), words written in a sentence (15 s, $r=0.39^{**}$; 60 s, $r=0.59^{**}$; ut, $r=0.52^{***}$), sentence writing quality (15 s, $r=0.39^{**}$; 60 s, $r=0.57^{**}$; ut, $r=0.56^{***}$), composition words written (15 s, $r=0.41^{**}$; 60 s, $r=0.63^{**}$; ut, $r=0.58^{***}$), composition quality (15 s, $r=0.38^{**}$; 60 s, $r=0.53^{**}$; ut, $r=0.60^{***}$)</p> <p>Alphabet letter writing fluency at beginning of kindergarten predicted end of year spelling (15 s, $\beta=0.32^{**}$; 60 s, $\beta=0.26^{\dagger}$; ut, $\beta=0.48^{***}$), sentence writing words written (ut, $\beta=0.23^{\dagger}$), sentence writing quality (ut, $\beta=0.36^{**}$), essay words written (ut, $\beta=0.37^{**}$) and essay quality (15 s, $\beta=0.2^{*}$; ut, $\beta=0.54^{***}$)</p> <p>Beginning of year alphabet letter writing fluency significantly explained additional variance in end of year spelling (15 s, $\Delta R^2=0.09^{**}$; 60 s, $\Delta R^2=0.04^{\dagger}$; ut, $\Delta R^2=0.13^{***}$), sentence writing number of words written (ut, $\Delta R^2=0.03^{*}$), sentence writing quality (ut, $\Delta R^2=0.07^{**}$), essay words written (ut, $\Delta R^2=0.08^{**}$), and essay quality (15 s, $\Delta R^2=0.04^{\dagger}$; ut, $\Delta R^2=0.16^{***}$)</p>

Table 2 (continued)

Number	Author, year, title	Design (quality rating)	Participants N, Mean age (SD)	Kindergarten handwriting measures/ interventions	Significant associations or effects of kindergarten handwriting skills on literacy ^a
16	Reuzel et al. (2019) <i>Exploring the relationship between letter recognition and handwriting in early literacy development</i>	Cross sectional (IIIB)	48, NR (NR)	Alphabetic letter writing fluency Letter writing fluency (copying pseudo letters) Visual motor skill—recognising and manipulating shapes to construct letters in order to copy a sample letter	Kindergarten associations between LNF and alphabetic letter writing fluency ($r = 0.638^{***}$) and recognising and manipulating critical features of letters (visual motor skill) ($r = 0.363^*$)
17	Eskberg, Zylstra and Pfeiffer (2016) <i>Effectiveness of a handwriting intervention with at-risk kindergartners</i>	Two group pre- post- test (IIB)	Intervention 23, 68.7 months (3.98); control 12, 71.8 months (5.19)	Intervention group received handwriting program (Size Matters) based on direct instruction for letter formation using motor learning and cognitive principles and including practice and engaging activities 2 X week for 16 weeks Control condition received classroom handwriting instruction	Greater gain for intervention group in upper case letter name recognition, $r = 2.34^*$; lower case letter name recognition, $r = 2.27^*$; and upper case letter sound recognition, $r = 2.46^*$

^a *p* values indicated as follows: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

an important inclusion in measures. For handwriting, this was assessed using either dictated letter or alphabet writing tasks. Both required fluent recall and retrieval of the letter form from memory. Not all authors employed timed tasks that required recall, such as handwriting fluency or phonological skills, again, reflecting the emerging nature of these skills in kindergarten. Reading measures used in kindergarten included word and nonsense word reading, rather than continuous text reading. For spelling and writing, developmental scoring was often used to ensure that emerging skills, such as partially correct spelling based on phonological knowledge, were incorporated.

Question 2: What were the observed relationships between handwriting ability and literacy in kindergarten?

A wide range of designs were included in the studies identified for this review, including one group and two group, cross sectional and longitudinal studies. As such, the Johns Hopkins Evidence Levels and Quality Ratings (Dang & Dearholt, 2017) were used in order to interpret and weight the significance and strength of the findings. According to the Johns Hopkins scale, designs that incorporate comparison groups, such as two group studies are rated as Level II evidence, while cross sectional or one group studies are considered weaker and rated as Level III (see Appendix 2). The Johns Hopkins scale has three ratings of quality, ranging from A—High quality, B—Good quality, and C—Low quality or major flaws. All of the studies in the review were rated as good quality (B) indicating: reasonably consistent results; sufficient sample size for the study design; some control, fairly definitive conclusions; and reasonably consistent recommendations based on fairly comprehensive literature review that includes some reference to scientific evidence (Dang & Dearholt, 2017). In this review we use the terms “stronger” or “high strength” to describe Level II evidence, and “weaker” or “lower strength” for Level III evidence. Overall, the strongest evidence was found for the relationship of letter writing fluency to literacy encompassing reading, writing and phonological skills. Evidence of lower strength was found for relationships between perceptual motor skills and literacy.

The relationship of letter writing fluency to literacy

Most support in the literature was found for an association between literacy and letter writing fluency measured in both dictated and alphabetic forms. Significant positive associations of letter writing fluency and significant effects of letter writing fluency intervention were found for a wide range of literacy factors in controlled intervention, longitudinal and cross sectional studies. The strongest evidence was found for the impact of letter writing fluency on writing composition and spelling, followed by reading (letter sound and name knowledge and fluency, nonsense word reading, real word reading). Further, a small amount of evidence was found for a relationship between letter writing fluency and phonological skills.

Writing composition and spelling

Three intervention studies rated as the highest level of evidence in this review explored the impact of a letter writing fluency based intervention on writing, particularly writing composition. The intervention in these studies was characterised by a focus on multi-sensory approaches to consolidating letter forming ability, that is, the ability to form letters from memory using a defined series of strokes and movements. In two studies, immediate post intervention effects on compositional writing were reported (words spelled correctly and number of ideas, Dolin (2016); and writing quality, Jones and Christensen (2012)). Additionally, two studies reported delayed effects of a letter writing fluency intervention on writing composition (grade five, conventions and linguistic concepts, Eidlitz-Neufeld (2003); grade one, recognizable words or sentences, number of sentences or thought units, basic punctuation, Jones and Christensen (2012)). Intervention study findings were supported by results from longitudinal studies. Alphabet writing fluency in kindergarten predicted grade one writing quality (for example, text structure, ideas, word choice and sentence fluency) and production (quantity of correct word sequences or number of words) (Kent et al., 2014; Malpique et al., 2020) and grade three exposition idea development (Kim et al., 2015). Beginning of year kindergarten alphabet letter writing fluency predicted and explained additional variance in end of year spelling, and sentence and composition writing quantity and quality (Puranik et al., 2017). Multi level modelling further demonstrated that kindergarten alphabet letter writing fluency predicted grade one writing quality (Malpique et al., 2020). Randomly sequenced dictated alphabet letter writing was significantly correlated with writing composition quality and quantity (Duncan, 2019).

In cross sectional studies conducted at varying points in the kindergarten year, alphabet writing fluency was significantly correlated with compositional sentence or text writing quantity and quality, generally rated for number of words, sentences and ideas (Kent et al., 2014; Kim et al., 2011; Puranik & Al Otaiba, 2012; Puranik et al., 2017). Additionally, Puranik et al. (2017) found beginning and end of year correlations of alphabet letter writing fluency with a standardised measure of writing. Three cross-sectional studies found alphabet writing fluency was uniquely and positively related to writing outcome (Kent et al., 2014; Kim et al., 2011; Puranik & Al Otaiba, 2012) and accounted for the most unique variance in number of words written (Puranik & Al Otaiba, 2012).

Spelling was further explored in relationship to letter writing fluency. Kindergarten dictated letter writing fluency predicted spelling in grade two (Karlsdottir & Stefansson, 2003), grade three (Eidlitz-Neufeld, 2003) and grade five (Eidlitz-Neufeld, 2003; Karlsdottir & Stefansson, 2003). Alphabet writing fluency at the beginning of kindergarten predicted end of year spelling (Puranik et al., 2017). Alphabet writing fluency measured using a range of times (15 s, 60 s and untimed, including dictated letter writing) was significantly correlated with spelling in seven studies (Duncan, 2019; Kent et al., 2014; Kim et al., 2011, 2014, 2015; Puranik & Al Otaiba, 2012; Puranik et al., 2017). Note that for these results, four were drawn from the same data set (Kim et al., 2011, 2014, 2015; Puranik & Al Otaiba, 2012).

Reading

Letter writing fluency intervention effects and associations were reported for foundational reading skills. Significant effects of a handwriting fluency intervention on letter name and sound knowledge were reported by Eckberg Zylstra and Pfeiffer (2016). This study was among the highest quality found in the review. Similar to the other intervention studies, this study was characterised by a focus on multi-sensory (motor learning and cognitive) approaches to consolidating letter forming ability. In support of this study, Eidlitz-Neufeld (2003) found that that letter form errors from dictated letter writing were significantly negatively correlated with letter name knowledge.

In other findings, kindergarten dictated letter writing fluency was found to predict grade two and grade five reading (Karlsdottir & Stefansson, 2003), as well as grade three and five word reading, nonsense word reading, and reading speed (Eidlitz-Neufeld, 2003). Further, dictated letter writing assessed for both legibility and speed was positively correlated with letter naming and nonsense word reading fluency (Frolek Clark & Luze, 2014). Alphabet writing fluency predicted grade one word reading (Malpique et al., 2020) and was also significantly associated with kindergarten letter name or sound knowledge (Kim et al., 2014; Reutzel et al., 2019), nonsense word reading (Kim et al., 2015; Puranik & Al Otaiba, 2012) and word reading (Kent et al., 2014; Kim et al., 2011, 2014, 2015; Malpique et al., 2020; Puranik & Al Otaiba, 2012). A one unit increase in word reading was significantly associated with a 0.1 increase in letter writing fluency (Malpique et al., 2017).

Phonological skills

Weaker (Level III) evidence was found for the relationships between letter writing fluency and phonological skills. Dictated letter writing was positively correlated with initial sound fluency and phoneme segmentation fluency (Frolek Clark & Luze, 2014). Alphabet writing fluency was significantly correlated with phonological awareness (Kim et al., 2014; Puranik & Al Otaiba, 2012).

The relationship of perceptual motor skills to literacy

Level III evidence was also found in support of a relationship between perceptual motor skills and literacy. The strongest evidence was found in an uncontrolled intervention study (Bazyk et al., 2009), however the weight of this evidence was lower than the letter writing intervention studies previously discussed. Evidence from cross-sectional studies was also found in support of the intervention study findings. No longitudinal data were identified.

Writing outcomes after perceptual motor skills intervention were identified by Bazyk et al. (2009). This study was a one group classroom based intervention focussed on the development of skills in fine and visual motor areas that may impact participation in writing activities. Significant gains were reported in correct letters written in each word in a dictated sentence.

Evidence was also found for a relationship between perceptual motor skills and aspects of reading. Bazyk et al. (2009) reported significant growth in letter knowledge after perceptual motor skills intervention as previously described. In cross sectional analysis visual motor integration was significantly correlated with nonsense word reading fluency (Frolek Clark & Luze, 2014) and letter naming fluency (Frolek Clark & Luze, 2014; Reutzler et al., 2019). Fine motor skills (in-hand manipulation and motor coordination) and visual perception were also significantly correlated with letter naming fluency and nonsense word reading (Frolek Clark & Luze, 2014).

The amount and weight of evidence for the relationship between perceptual motor skills and phonological skills was low, with cross sectional evidence for a relationship between perceptual motor skills and phonological skills reported in one study. Specifically, visual motor integration, fine motor skills (in-hand manipulation), motor coordination and visual perception were associated with initial sound fluency and phoneme segmentation fluency (Frolek Clark & Luze, 2014).

Discussion

This systematic review sought to examine the relationship between handwriting and literacy for kindergarten. The scope of the review included analysis and grouping of measurements of both handwriting and literacy in kindergarten, and analysis of the relationships between handwriting and literacy factors. This study identified two categories of handwriting measurement (letter writing fluency and perceptual motor abilities) and five categories of literacy measurement (letter name and sound knowledge, phonological skills, word reading, writing composition and spelling). The findings of this review provide higher strength evidence for the associations with, and effects of, letter writing fluency on literacy, however perceptual motor abilities also showed evidence of weaker relationships. These findings are instructive in progressing understanding of handwriting fluency measurement, the role of handwriting in literacy, and handwriting intervention approaches that may impact literacy in kindergarten.

Measurement of handwriting and literacy in kindergarten

Measurement of handwriting ability in kindergarten is an important consideration, given the relationships with literacy identified in this review. By far the most common measure of handwriting used in the included studies was a measure of letter writing fluency, generally collected through timed alphabet testing. Timed alphabet writing generally relies on remembering and reproducing letters in alphabetic sequence, and combines aspects of letter legibility in scoring. For example, in a number of studies, letters received a score of zero for an illegible, out of order, cursive or upper case letter, half a point for a poorly formed or reversed letter and one point for a correctly formed and ordered letter (Kent et al., 2014; Kim et al., 2011, 2015; Malpique et al., 2017). Puranik et al. (2017) devised a coding system in which four identified errors contributed to the point score, based on the number

or the type of errors made. Possible errors included poor form or control reversal or inversion, upper case or unrecognisable letters. Floor effects, and limitations of timed alphabet measures as predictors of kindergarten literacy have been reported (Puranik et al., 2017). Dictated letter writing measures, or those that do not require alphabetic sequencing, partially address the limitations of alphabet knowledge and timing constraints, however most measures using this method also used a rubric that combine accurate memory recall of the letter with aspects of letter appearance, as for the alphabet writing tests, for example, Reutzler et al. (2019). As scoring for memory recall and legibility of letters is combined, it is not clear from these rubrics which factor has the greatest impact on letter writing fluency – alphabet knowledge, letter sound knowledge, or the impact of perceptual motor factors such as fine and visual motor skills that may produce legibility errors. Perceptual motor measures also aim to record a range of fine motor, visual motor, perceptual and motor coordination skill that may impact handwriting, but do not account for the cognitive processes inherent in fluent handwriting. Measures of handwriting fluency for kindergarten may need refinement to capture the contribution of all skills that impact fluency including phonemic ability, memory of letter forms, and perceptual motor skill including visual motor ability (Abbott & Berninger, 1993; Cartmill et al., 2009; Wolf et al., 2017). Measures may need to be developed that capture the impact of both perceptual motor skill and fluency processes on handwriting in order to gain a clearer understanding of relationships with literacy.

Evidence for handwriting as a facilitator of literacy in kindergarten

Two distinct elements of handwriting were identified in this review – letter writing fluency and perceptual motor skills. Literacy measurement encompassed reading (letter name and sound knowledge and word reading), writing (writing composition and spelling), and phonological skills. Kindergarten letter writing fluency (writing legible letters from memory) was found to have a strong relationship to both reading and writing. Controlled studies that utilised a letter writing fluency development intervention reported significant gains in writing composition (Dolin, 2016; Eidlitz-Neufeld, 2003; Jones & Christensen, 2012) and reading (letter identification; Eckberg Zylstra & Pfeiffer, 2016). Further evidence was found supporting these relationships in longitudinal and correlational analyses (for example, Duncan, 2019). Letter writing fluency has an established relationship with written composition quantity and quality (Alves et al., 2016; Berninger et al., 1997; Feng et al., 2019; Graham et al., 1997, 2000; Jones & Christensen, 1999; Kim et al., 2018; Limpo & Alves, 2013). This relationship is explained by cognitive load theory, in which automation of handwriting enables working memory to be available for more complex writing tasks such as ideating and planning (McCarney et al., 2013; McCutchen, 1996). The current review documents the evidence for this handwriting and writing composition effect in kindergarten children. Weaker evidence was also found in this review for relationships between letter writing fluency and reading. Evidence for the interrelationship of reading and handwriting is accumulating, with researchers finding that writing letters by hand activates reading circuits in the brain (James

& Engelhardt, 2012). This suggests that handwriting has a role to play in facilitating relationships between letter names, sounds and forms, contributing to both reading and writing abilities. Further investigation of the impact of letter writing fluency on reading is indicated from this review, as the preliminary evidence documented here is supportive of the impact of letter writing fluency on both reading and writing in kindergarten.

Weaker evidence was found for relationships between perceptual motor skills (fine motor, visual motor, perceptual and motor coordination) and literacy (letter knowledge, spelling, word reading and phonological skills). An uncontrolled study found that after perceptual motor intervention, gains were made in sentence writing and letter identification (Bazyk et al., 2009). As for letter writing fluency studies, further evidence supportive of the relationship was found in correlational studies. Similar associations between perceptual motor skills and literacy found in this review have been reported in preschool studies. For example, Suggate et al. (2019) found that for preschool children in Germany, fine motor skills (manipulation) did not play a role in early reading development, but graphomotor skills (copying pseudo letters) did. In another study, preschool children who learnt to write letters using pencil and paper rather than by typing or touch screen showed greater performance in both visual motor skills and letter recognition (Mayer et al., 2019). This suggests a role for a blend of perceptual and motor factors in letter writing fluency, with possible impacts on reading. Similarly, Cameron et al. (2012), measured fine motor skills prior to formal schooling and found that a combination of early fine motor abilities (building with blocks, copying shapes with a pencil, and drawing a person) predicted higher achievement on kindergarten entry tests including word reading and phonological skills. Further, literacy improvement across kindergarten was greater for children who had stronger design copy skills at preschool assessment. As noted, the weight of evidence for the role of perceptual motor skills in literacy for kindergarten is lower than for letter writing fluency, however the findings, combined with findings of studies from other age groups, suggest these skills warrant further attention as factors in literacy ability.

Handwriting intervention elements and literacy in kindergarten

In this review, studies with the highest level of evidence used a controlled, two group evaluation of a handwriting intervention and reported improved literacy outcomes across reading and writing areas (Dolin, 2016; Eckberg Zylstra & Pfeiffer, 2016; Eidlitz-Neufeld, 2003; Jones & Christensen, 2012). Each of the four studies used differing intervention methodologies, but all focussed on promoting letter writing fluency using age appropriate activities and including modelling (explicit instruction of letter, sound and form correspondences), multi-sensory activities to promote letter writing (for example, writing with finger in the air, tracing letters in sand), and engaging a range of sensory modalities to promote fluency (for example, auditory cues, directional arrows, visual modelling). What the description of methodologies suggests is that researchers combined both perceptual motor and letter writing fluency factors in intervention. It is possible that the nature of the activities facilitated

the development of perceptual motor abilities necessary for handwriting. Given the evidence found in this review for strong relationships of letter writing fluency with literacy, and weaker, but significant, relationships of perceptual motor skills with literacy, it is possible that both intervention elements, to unspecified degrees, impacted the literacy outcomes. Another, lower level intervention study (one group pre- post-test) focussed on development of perceptual motor contributors that may impact participation in writing (Bazyk et al., 2009). This study found greater than typical maturational development in the perceptual motor skill areas assessed, and significant growth in sentence writing and letter identification. The impact of perceptual motor skill development on literacy is still unclear, but emerging evidence is supportive of a relationship (Cameron et al., 2012, 2015, 2016; McClelland & Cameron, 2019). In summary, intervention studies offer some support for inclusion of both perceptual motor skill development and letter writing fluency as part of effective handwriting intervention that may have positive impacts on literacy. The preliminary evidence found in this study, combined with learnings from younger age groups as previously discussed are supportive of a focus on perceptual motor skills development in the early years and in conjunction with the beginning stages of handwriting instruction. Further study of the role of perceptual motor skills in early handwriting acquisition is needed before any definitive conclusions can be drawn.

Proposed mechanisms for the relationships between handwriting and literacy found in this review

As previously described, the mechanism for the effect of handwriting on writing has been explained through capacity theory, whereby automaticity of some processes allows for application of cognitive resources to higher order tasks involved in written composition, such as generating ideas and planning. The effects of handwriting on writing composition in kindergarten found in this review are likely to be a result of the same mechanisms, with studies in this review demonstrating relationships between kindergarten handwriting automaticity and concurrent or later writing composition (for example, Malpique et al., 2020; Puranik & Al Otaiba, 2012). Similarly, handwriting fluency was associated with improved spelling, and this association may relate to automaticity processes as well. As most studies used a developmental scale to assess spelling, rather than a dichotomous right/wrong method, the findings suggest that fluent letter writing may be supportive of phonetic or invented spelling, as letter sound correspondences are more retrievable, and therefore more readily available to be applied in invented spelling. Spelling occurs through encoding of “sounds to signs” (Oddsdóttir et al., 2021, p. 393) and it is suggested that improved handwriting fluency supports this encoding process. A recent longitudinal study of five and six year olds is supportive of the notion that writing words may facilitate the development of orthographic knowledge, with handwriting skills accounting for unique variance in the growth of spelling abilities (Pritchard et al., 2021). Other studies have also identified a relationship between the motor processes that occur with handwriting, and the establishment of orthographic representations for words used in

spelling (Lavoie et al., 2020; Ouellette & Tims, 2014). Modelling conducted by Duncan (2019) determined that a combined transcription measure, comprising both handwriting and spelling, significantly impacted kindergarten writing composition quality and productivity (number of words and ideas), also suggesting an interrelationship of these factors in beginning writing. Given the relationship of handwriting fluency to emergent spelling identified in this review, it may be possible that a strong basis of letter writing fluency in kindergarten is supportive of emergent spelling, contributing to the effects of both spelling and handwriting on writing outcomes observed in kindergarten and grade one children (Kim & Park, 2019; Puranik & Al Otaiba, 2012). Further research of handwriting and spelling relationships is indicated.

The nature of a causal relationship of handwriting to reading is less understood, however evidence from functional magnetic resonance imaging has shown that the act of writing by hand has an activating effect on brain regions associated with reading (James & Engelhardt, 2012). The majority of intervention studies in this review reported effects of handwriting intervention on writing outcome, with only one intervention study reporting effects on reading (Eckberg Zylstra & Pfeiffer, 2016). More kindergarten intervention studies are needed to explore the effect of handwriting on reading as well as writing.

Relationships of handwriting to literacy may be stronger in kindergarten than in subsequent years. For example, Kent et al. (2014) found that attention, higher order literacy (reading and spelling) and alphabet writing fluency were uniquely and positively related to kindergarten writing outcomes, but only attention and the higher order literacy factor predicted grade one outcomes. Also, Kim et al. (2015), found correlations at kindergarten level between alphabet writing and a literacy variable (six factors of reading and spelling combined), but only a combination of oral language and the combined literacy measure predicted grade three exposition writing. These studies may indicate that the relationships between alphabet writing and literacy are perhaps strongest in the kindergarten year, as letter writing fluency directly impacts emerging abilities required for early reading and writing tasks, such as decoding and invented or phonetic spelling. More research is needed to understand the effect of handwriting in the kindergarten year.

Finally, it is conceived, and preliminarily supported by this review, that perceptual motor skills including fine motor and visual motor abilities may facilitate and support the practice of letter writing. Through this practice, stronger relationships between letter name, sound and form may be made, possibly facilitating improvements in emergent spelling, reading and writing. Further, enhanced perceptual motor abilities in preschool are also related to greater abilities in print knowledge and phonological awareness, suggesting a role for the development of perceptual motor skills to support literacy (Cameron et al., 2015). The theory of cognitive load is cited as one explanation for these effects, with stronger visual motor abilities enabling limited cognitive resources to be directed to aspects of a task that are more complex, rather than to the inherent perceptual motor requirements of the task (Cameron et al., 2016). Both perceptual motor and cognitive development in kindergarten may impact handwriting skills, and addressing all factors in intervention approaches could lead to both handwriting and subsequent literacy gains.

Study limitations

This study sought to explore relationships between handwriting fluency and literacy in the first year of school. As such, some relevant factors that impact early literacy are not covered in this study. Clearly there are many factors at play in the development of literacy, however, this review clarifies understanding of the relationship of handwriting to literacy. The results of this systematic review can only be considered within the scope explored, in order to direct further study into the role of handwriting fluency in literacy. While there are other important contributors to literacy that were outside the scope of this review, the results nonetheless provide important direction to future intervention studies, by highlighting the role of automatic, fluent letter writing from memory in relation to a wide range of literacy outcomes. One important consideration in interpretation of the results of this review is that the included studies used varying designs, such as one group, two group and cross sectional studies. A quality rating system to weight the strength of evidence was used in order to interpret the study results. The rating process weighted two group intervention studies as having higher strength of evidence, however, there is a risk that in studies with small sample sizes, effect sizes could be increased, limiting the conclusions drawn in this review. The limitations discussed indicate that the findings of this review should be considered indicative, with further research and reviews needed to confirm the results. Future intervention studies should seek to combine knowledge of contributors to handwriting for beginning writers, both from a perceptual motor and cognitive perspective, in order to refine interventions and further explain the role that handwriting fluency, per se, may play in literacy development. Finally, it is noted that researchers have identified other contributing factors to writing outcomes including oral language (Kim et al., 2011) and attention (Kent et al., 2014) and that alphabet letter writing fluency is just one aspect of models that have been devised to explain literacy outcomes. Given the accessibility of handwriting intervention approaches with a focus on foundational skills and fluency development, it is possible that attention to this one aspect could yield gains for emergent literacy. However, more evidence is needed to direct future intervention and classroom approaches. Handwriting, specifically letter writing fluency, appears to be a crucial contributor to kindergarten literacy.

Conclusion

This review sought to quantify and qualify the characteristics of measures used to assess handwriting and literacy in kindergarten, and to explore the relationships between different skills in these two areas. The results are supportive of the existence of a relationship between handwriting and literacy in kindergarten. While it appears letter writing fluency has the strongest relationship with literacy, evidence of relationships is also available for less frequently examined aspects of handwriting function such as perceptual motor ability. Intervention studies with the strongest research design showed that focussing on handwriting fluency can impact foundational reading skills such as letter identification, and writing skills such as composition. If the handwriting and literacy relationships reported in this review can be further substantiated in whole class intervention studies, it may be possible to support kindergarten literacy through a readily available classroom means—effective handwriting instruction.

Appendix

See Tables 3 and 4.

Table 3 Groupings for handwriting and literacy used in included studies

Grouping	Definition	Methods of measurement and references
Handwriting		
Letter writing fluency, either dictated ($n=5$) or alphabetic ($n=11$)	Dictated letter writing fluency is the ability to recall and write dictated, non-alphabetically sequenced letters	Scoring combined aspects of appearance (legibility) as well as memory recall of dictated letter (fluency), for example, criteria used by Frolek Clark and Luze (2014) included: matches dictated letter, correct line placement, no large gaps, correct orientation, and recognisable out of context (Dolin, 2016; Duncan, 2019; Eidlitz-Neufeld, 2003; Frolek Clark & Luze, 2014; Karlsdottir & Stefansson, 2003)
	Alphabetic letter writing fluency is alphabet writing from memory, with variations in the amount of time allowed for writing	Methods for scoring included number of recognisable (legible), alphabetically sequenced letters written in varying time periods (15 s, 60 s and untimed). Features that were generally required included recognisability of the letter, correct orientation, and correct alphabetic sequence (Dolin, 2016; Jones & Christensen, 2012; Kent et al., 2014; Kim et al., 2011, 2014, 2015; Malpique et al., 2017, 2020; Puranik & Al Otaiba, 2012; Puranik et al., 2017; Reutzel et al., 2019)
Perceptual motor skills ($n=4$)	A range of abilities across visual, perceptual and motor systems including fine motor skills (movement skills of the small muscles of the hand, generally requiring manipulation of a tool or object), visual motor integration (VMI) (coordination of eye and hand skills to enable tasks such as copying), motor coordination (coordination of writing movements, such as tracing within lines) and visual perception (discrimination between shapes)	Fine motor (Bazyk et al., 2009; Frolek Clark & Luze, 2014) VMI (Bazyk et al., 2009; Frolek Clark & Luze, 2014; Karlsdottir & Stefansson, 2003; Reutzel et al., 2019) Motor coordination and visual perception (Frolek Clark & Luze, 2014)
Literacy		

Table 3 (continued)

Grouping	Definition	Methods of measurement and references
Letter name and/or sound knowledge (<i>n</i> =9)	Verbal identification of as many mixed upper and lower case and randomly ordered letter names and/or sounds as possible	Performance was untimed or timed (generally one minute duration) Timed (Dolin, 2016; Frolek Clark & Luze, 2014; Kim et al., 2014; Reutzel et al., 2019) Untimed (Bazyk et al., 2009; Eckberg Zylstra & Pfeiffer, 2016; Eidlitz-Neufeld, 2003; Karlsdottir & Stefansson, 2003; Malpique et al., 2020)
Phonological skills (<i>n</i> =5)	The ability to hear and manipulate sounds, for example, identification of the first sound of a spoken word, breaking a word into its phonetic components, or blending segments of a word together to say the whole word	Initial sound fluency (identification of first sound of a spoken word), phoneme segmentation fluency (breaking a whole spoken word into its phonemic components) (Dolin, 2016; Frolek Clark & Luze, 2014) Phoneme blending (joining individual sounds to say a word) (Kim et al., 2014; Puranik & Al Otaiba, 2012) Elision (listen to a word and then say it after deleting a part or sound) (Kim et al., 2014; Puranik & Al Otaiba, 2012) Unspecified (Malpique et al., 2020)
Word reading (<i>n</i> =11)	Nonsense word or pseudo word fluency is the ability to read words that can be decoded by applying the alphabetic principle. Real word reading includes both decodable and non-decodable (sight) words	Reading skills include timed or untimed sounding out of decodable real or nonsense word and recognition of sight or non-decodable words Timed nonsense word fluency (Dolin, 2016; Frolek Clark & Luze, 2014) Untimed nonsense word fluency (Eidlitz-Neufeld, 2003; Kent et al., 2014; Kim et al., 2014, 2015; Puranik & Al Otaiba, 2012) Timed and untimed real word reading (Eidlitz-Neufeld, 2003; Kent et al., 2014; Kim et al., 2011, 2014, 2015; Malpique et al., 2017, 2020; Puranik & Al Otaiba, 2012) Reading accuracy and comprehension (Eidlitz-Neufeld, 2003; Karlsdottir & Stefansson, 2003)

Table 3 (continued)

Grouping	Definition	Methods of measurement and references
Writing composition ($n = 10$)	Composing a sentence, story or exposition based on a writing prompt (either picture and word or prompt topic)	Rubrics devised measured quantity and quality of writing and included a combination of number of words and/or sentences written (Dolin, 2016; Duncan, 2019; Jones & Christensen, 2012; Kent et al., 2014; Kim et al., 2011; Malpique et al., 2020; Puranik & Al Otaiba, 2012; Puranik et al., 2017), spelling (sometimes using partial scoring for phonetically correct attempts) (Dolin, 2016; Duncan, 2019; Malpique et al., 2020; Puranik et al., 2017), number of ideas or units of thought expressed (Dolin, 2016; Jones & Christensen, 2012; Kent et al., 2014; Kim et al., 2011; Malpique et al., 2020; Puranik & Al Otaiba, 2012), sentence organisation, complexity or sequencing (Dolin, 2016; Duncan, 2019; Eidlitz-Neufeld, 2003; Kent et al., 2014; Malpique et al., 2020; Puranik et al., 2017), punctuation and/or grammar (Duncan, 2019; Eidlitz-Neufeld, 2003; Jones & Christensen, 2012; Malpique et al., 2020; Puranik et al., 2017), vocabulary (Kent et al., 2014; Malpique et al., 2020), text structure/form/organisation (Eidlitz-Neufeld, 2003; Kim et al., 2015; Puranik et al., 2017), correct word sequences (use of punctuation to delineate one sentence from the next, syntactically and semantically correct ordering of words and adjacent words spelled correctly) (Dolin, 2016; Kent et al., 2014; Malpique et al., 2020), and idea development, meaning or relevance of writing to the prompt (Duncan, 2019; Kim et al., 2015; Puranik et al., 2017)

Table 3 (continued)

Grouping	Definition	Methods of measurement and references
Spelling (word and sentence) ($n = 11$)	The ability to translate spoken, dictated words into writing. Can be single words or sentences	For single word spelling, whole words were scored dichotomously as right or wrong (Dolin, 2016; Duncan, 2019; Eidlitz-Neufeld, 2003; Karlsdottir & Stefansson, 2003; Kent et al., 2014; Kim et al., 2011; Puramik et al., 2017) and/or on developmental scales that allowed for gradations based on phonemic correctness (Kent et al., 2014; Kim et al., 2014, 2015; Puramik & Al Otaiba, 2012). For dictated sentence writing, number of correct letter sounds written was recorded (Bazyk et al., 2009)

Table 4 Risk of Bias Rating—Johns Hopkins Evidence Based Practice

Author (first author only), year	Level of evidence		Quality review										Level of evidence and quality rating*		
	Manipulation of independent variable	Control group?	Participants assigned to intervention or control	Identification of problem and gaps in knowledge	Study purpose clear	Current literature review (>50% sources <5 years old or seminal)	Sufficient sample size	Similar control and intervention demographics and settings	Clearly described data collection methods	Instruments reliable	Validity discussed	Results clearly presented		Limitations addressed	Conclusions based on results
Bazyk et al. (2009)	Y	N	NA	Y	Y	N	Y	NA	Y	P	N	Y	Y	Y	IIIB
Dolin 2016	Y	Y	N	Y	Y	N	Y	Y	Y	P	Y	Y	Y	Y	IIB
Duncan 2019 (Study 2)	N	N	NA	Y	Y	Y	Y	NA	Y	P	P	Y	Y	Y	IIIB
Eidlitz-Neufeld (2003) (Study 1)	N	N	N	Y	Y	N	Y	NA	Y	P	N	Y	Y	Y	IIIB
Eidlitz-Neufeld (2003) (Study 2)	Y	Y	N	Y	Y	N	Y	Y	Y	P	N	Y	Y	Y	IIB
Frolek Clark and Lutz (2014)	N	N	NA	Y	Y	N	Y	NA	Y	P	Y	Y	Y	Y	IIIB

Table 4 (continued)

Author (first author only), year	Level of evidence				Quality review							Level of evidence and quality rating*			
	Manipulation of independent variable	Control of independent variable?	Participants randomly assigned to intervention or control	Identification of problem and gaps in knowledge	Study purpose clear	Current literature review (> 50% sources < 5 years old or seminal)	Sufficient sample size	Similar control and intervention demographics and settings	Clearly described data collection methods	Instruments reliable	Validity discussed		Results clearly presented	Limitations addressed	Conclusions based on results
Jones and Christensen (2012)	Y	Y	N	Y	Y	N	Y	Y	Y	NR	N	Y	N	Y	IIB
Karlsdotir and Stefansson (2003)	N	N	NA	Y	Y	N	Y	NA	Y	NR	N	Y	Y	Y	IIIB
Kent et al. (2014)	N	N	NA	Y	Y	Y	Y	NA	Y	Y	N	Y	Y	Y	IIIB
Kim et al. (2014)	N	N	NA	Y	Y	N	Y	NA	Y	P	N	Y	Y	Y	IIIB
Kim et al. (2011)	Y	N	NA	Y	Y	Y	Y	NA	Y	P	N	Y	Y	Y	IIIB
Kim et al. (2015)	Y	N	NA	Y	Y	Y	Y	NA	Y	P	N	Y	Y	Y	IIIB
Malpique et al. (2020)	N	N	NA	Y	Y	Y	Y	NA	Y	P	P	Y	Y	Y	IIIB

Table 4 (continued)

Author (first author only), year	Level of evidence			Quality review											
	Manipulation of independent variable	Control of independent variable?	Participants randomly assigned to intervention or control	Identification of problem and gaps in knowledge	Study purpose clear	Current literature review (> 50% sources < 5 years old or seminal)	Sufficient sample size	Similar control and intervention demographics and settings	Clearly described data collection methods	Instruments reliable	Validity discussed	Results clearly presented	Limitations addressed	Conclusions based on results	Level of evidence and quality rating*
Malpique et al. (2017)	N	N	NA	Y	Y	Y	Y	NA	Y	P	N	Y	Y	Y	IIIB
Puranik and Al Otaiba (2012)	N	N	NA	Y	Y	Y	Y	NA	Y	P	N	Y	Y	Y	IIIB
Puranik et al. (2017)	N	N	NA	Y	Y	Y	Y	NA	Y	Y	P	Y	Y	Y	IIIB
Reutzel et al. (2019)	N	N	N	Y	Y	N	Y	NA	Y	Y	N	Y	Y	Y	IIIB
Eckberg Zylstra and Pfeiffer (2016)	Y	Y	N	Y	Y	Y	Y	Y	Y	P	N	Y	Y	Y	IIB

*Level of evidence: I—RCT, II—quasi experimental, III—non experimental; quality rating: A—high, B—good, C—Low; Coding for level of evidence and quality items: Y = yes, N = no, P = partial

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